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Integrating Color Theory Into Smart Desk Lighting System for Enhanced Productivity and Cognitive Function in Work Environments

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ABSTRACT

The integration of color theory into workspace lighting design has the potential to enhance productivity, cognitive function, and overall well-being. This study explores how lighting influences focus, mood, and comfort, focusing on principles of color theory and user-centered design to create effective workspace solutions. As remote work and flexible office arrangements grow, adaptable and ergonomic lighting systems are becoming increasingly important. Lighting characteristics such as color temperature and hue significantly impact mental and physical states while cooler tones, like blue and white, improve focus and task accuracy, while warmer tones, like amber, promote relaxation and reduce stress. This study's user surveys identified common challenges, including limited adjustability, excessive glare, and a lack of personalization, with many participants reporting dissatisfaction due to these issues. A total of 117 participants, representing diverse age groups, professions, and work environments, were surveyed to capture a broad range of perspectives from individuals who commonly use workspaces, making them the ideal target group for this study. Identified key features provided the fundamental knowledge regarding the requirements and their impact on the design and development of the workplace lighting solution. We are proposing a smart desk lighting system designed around user needs and color theory principles. Key features include customizable brightness, color temperature, and hue, along with pre-set configurations for tasks such as reading, computer work, and relaxation. Ergonomic considerations, such as glare reduction and flexible positioning are central to the success of the design. The study is in its developmental stages and the content of this publication covers the importance of adaptable and user-focused lighting solutions while the prototyping stage will be covered in the future publications. By leveraging color theory and ergonomic design, this research aims to bridge the gap between functional aspects and aesthetic appeal, providing a framework for innovative workspace lighting that supports productivity, cognitive performance, and overall health. These insights pave the way for future prototype development and testing, redefining how lighting integrates into modern workspaces.

Keywords: Workspace lighting design, Color theory, User-centered design, Adjustable lighting and ergonomics

INTRODUCTION

The insurgence of remote work has called upon the need for flexible office arrangements. Hybrid work settings have emphasized the critical importance of work environments that support productivity, health, and well-being (ILO, 2020). Lighting, a fundamental aspect of workspace design, plays a vital role in shaping focus, mood, and physical comfort. The effect of lighting design thus needs further probing. Poor lighting conditions can lead to significant issues, including eye strain, diminished cognitive performance, and long-term health effects such as disrupted circadian rhythms and sleep patterns (Smolders & de Kort, 2014). Compounding these challenges, glare from poorly designed lighting systems can strain the eyes and even trigger ocular migraines, further hindering productivity and well-being (IES, 2021). Moreover, inadequate lighting fosters stress and fatigue, ultimately reducing engagement and creating less productive workspaces (Bao et al., 2021).

In response to these challenges, the fields of industrial design and human factors have increasingly prioritized user-centered environments that cater to individual needs (Norman, 2013). This research aims to contribute to that effort by studying and commenting on the deficiencies in traditional workspace lighting systems through exploring the integration and applicability of color theory principles. The study focuses on two factors, namely color temperature and hue, and how they contribute to the development of adaptable, ergonomic, and visually appealing solutions that redefine workspace lighting. The objective is to examine how lighting influences cognitive performance and emotional states, using insights from literature, user surveys, and planned in-person testing to conceptualize a smart desk lighting system tailored to a variety of tasks and user preferences.

BACKGROUND

On average, professionals spend over six hours daily at a desk, often more in remote or office-based roles (BLS, 2021). Given this prolonged exposure, lighting significantly impacts productivity, comfort, and health. It can reduce eye strain, fatigue, and cognitive load, while influencing mood and focus (Smolders & de Kort, 2014). Poor lighting—particularly inadequate brightness or excessive glare—has been linked to reduced concentration and heightened stress (IES, 2021). The COVID-19 pandemic accelerated the shift to hybrid work, pushing individuals and companies to adapt to remote-friendly environments (ILO, 2020). As a result, workspace design, especially lighting, became essential for maintaining well-being and efficiency in home offices.

Lighting strongly affects human behavior and performance, with color psychology and lighting physics offering important insights. Blue tones are linked to focus and alertness, while warmer amber tones support relaxation and creativity. **Color temperature** (Figure 1), measured in Kelvin (K), provides a framework for evaluating light's warmth or coolness. Cooler tones (5000–6500K) promote concentration and task performance, while warmer tones (2700–3000K) foster calm environments. Additionally, **illuminance** (Figure 2), measured in lux, influences visual comfort and task efficiency.

Lighting also regulates circadian rhythms—our internal clock—affecting sleep-wake cycles and cognitive function.

Extensive research confirms lighting's effects on cognition. Cooler light tones enhance focus, accuracy, and alertness. Smolders and de Kort (2014) found that exposure to higher color temperatures during desk tasks improved sustained attention and task completion rates by 15% compared to neutral white light. Warmer tones help reduce stress and support creative or restorative tasks. Bao et al. (2021) demonstrated that dynamic RGB (Red, Green, Blue) lighting increased mood satisfaction by approximately 20% compared to static lighting setups.

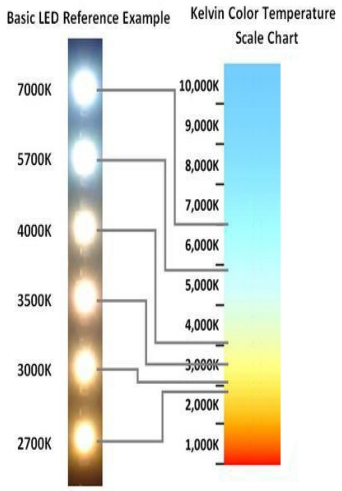

Figure 1: Kelvin color temperature scale chart (Behavioral Health Facility Consulting, 2020).

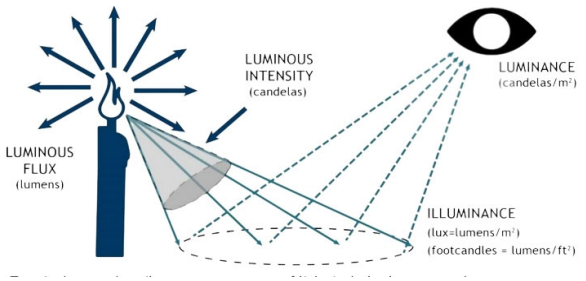

Figure 2: Terminology to describe various measures of light includes luminance, luminous intensity, luminous flux, and illuminance (CK Associates, 2020).

Despite technological advances, current lighting systems often lack adaptability and personalization. Many remain static and fail to meet the diverse needs of users. According to the Illuminating Engineering Society, over 70% of employees express dissatisfaction with workspace lighting due to factors like glare, poor adjustability, and lack of visual variety (IES, 2021).

These gaps reveal opportunities to integrate dynamic customization and color theory into lighting design—balancing functionality with aesthetic value.

Current workspace and study environments (Figure 3) often suffer from suboptimal lighting—insufficient brightness, glare, and limited adaptability—which contribute to eye strain, fatigue, and diminished cognitive performance (Smolders & de Kort, 2014). These issues largely stem from traditional lighting approaches that prioritize general illumination over task-specific or user-centered solutions (Boubekri, 2020).

The proposed smart desk lighting system addresses these challenges by incorporating adjustable brightness, task-specific lighting profiles, and dynamic RGB customization. It supports both comfort and performance by enabling users to shift lighting conditions based on task and time of day. Research suggests that tailored lighting improves mood and productivity by up to 20% (Bao et al., 2021). By applying ergonomic lighting principles—such as color temperature modulation and seamless profile transitions—this solution provides a holistic, human-centered approach to modern workspace lighting.

Figure 3: Two views of a current home-workspace setup. Note: this image was taken by the author (2024).

METHODOLOGY AND RESULTS

This study was approved by the University of Houston's Institutional Review Board (IRB) under Study #4998 and adhered to all ethical guidelines for human subjects' research. To explore user workspace preferences and the consequent challenges, a comprehensive survey was conducted with over 100 participants from various professions, age groups, and workspace environments. Recruitment took place via online platforms such as LinkedIn,

Facebook, and Instagram, as well as academic institutions, and workplace networks, ensuring diverse perspectives. The survey used a mix of multiple-choice and open-ended questions to collect quantitative and qualitative data. Key areas of investigation included desk usage patterns, current workspace lighting, lighting challenges, and preferences for ideal lighting system features.

Participants highlighted several challenges, with 91% working at their desks for over five hours daily. Common issues included excessive glare, poor adjustability, and insufficient brightness. 51% of respondents noted difficulty balancing natural and artificial light, particularly those working near windows who struggled with excessive glare during the day and dim lighting in the evening. Preferences emphasized adjustable brightness and color temperature, with 62% prioritizing these features, and 74% expressing interest in RGB lighting for mood enhancement (Figure 4).

Analysis revealed a growing demand for lighting systems that provide emotional benefits in addition to functional utility which was not expected at the beginning of the study. Many participants valued mood-enhancing features like warm, soft hues to create a calming workspace. The importance of seamless transitions between lighting profiles for different tasks was another key finding, which aligns with the circadian-friendly principles.

These results informed the design of a smart desk lighting system emphasizing adjustability, dynamic features, and integration of natural and artificial light. The findings highlight the necessity of a user-centered approach that balances functional, cognitive, and emotional needs.

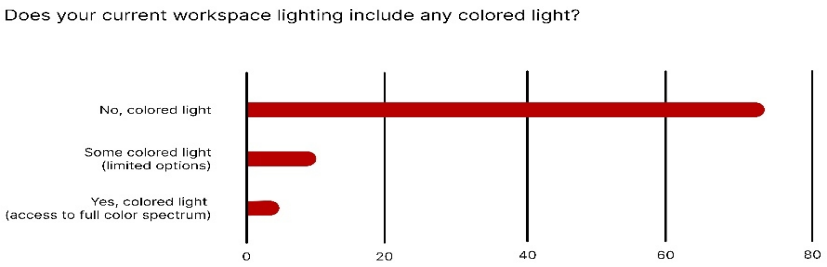

Figure 4: Does your current workspace lighting include any colored light (Study Survey Analytics, 2025).

LIGHTING SYSTEM DESIGN

The proposed smart desk lighting system is an innovative, multi-component solution rooted in user insights and comprehensive research (see the background). The proposed design modifies the current desk lighting in three major ways. First, adjustable desk lamps provide focused task lighting, eliminate shadows and improve visibility. Second, a desk light bar ensures

uniform workspace illumination, addressing inefficiencies caused by single-source setups. Third, ambient lighting is provided by a floor lamp, reducing contrast and eye strain, while wall panels with RGB lighting align with users' circadian rhythms and mood preferences.

Customization is central to the design, offering adjustable brightness, color temperature, and hue to meet diverse user needs. Pre-set configurations tailored for productivity, relaxation, and creativity simplify interaction while aligning lighting with specific tasks. Ergonomic considerations, such as glare reduction and flexible positioning, further enhance comfort and usability.

EXPERIMENT PROTOCOL DESIGN

To evaluate the effectiveness of the prototype lighting system, an in-person testing protocol has been developed. This portion of the study was still in progress at the time of this writing, with testing scheduled for Spring 2025.

Participants would engage in a series of tasks under three distinct lighting profiles, each designed to evaluate the impact of different lighting conditions on performance and comfort. The first profile, **Baseline Light**, utilizes the existing room lighting to serve as a control condition, representing a typical, unoptimized workspace setting. The second profile, **Task-Optimized Light**, features white light specifically tailored for task-focused activities, ensuring clarity and precision for tasks requiring sustained attention. Finally, the third profile, **Enhanced Task Light**, builds on the task-optimized setup by incorporating subtle colored lighting to align with principles of color theory, aiming to enhance mood and cognitive engagement while supporting specific task requirements. Together, these profiles provide a comprehensive framework for assessing the effectiveness of lighting in diverse work scenarios.

To ensure the validity of the testing conditions, all environmental factors apart from lighting remain consistent throughout the study; the surrounding space, including room layout, furniture arrangement, desk setup, and seating position, remains unchanged for all participants, allowing the experiment to isolate the impact of lighting variations without interference from external spatial variables.

The selected tasks are designed to evaluate the impact of different lighting profiles on common workspace activities, providing a comprehensive assessment of productivity, comfort, and cognitive performance. Chosen for their relevance to typical workspace tasks like reading, typing, and problem-solving, these activities allow for a thorough evaluation of lighting's effects, aligning with human-centered design principles (Norman, 2013).

The first task, a) **Reading on a Monitor**, requires participants to read a short, uniformly formatted paragraph displayed on a monitor. Afterwards, they would have to answer three comprehension questions to assess their focus, readability, and cognitive retention under varying lighting conditions. This task highlights the importance of minimizing glare and optimizing illumination for prolonged screen use. Similarly, b) **Typing on a Computer** evaluates the participants' ability to transcribe a paragraph read aloud to them. By focusing on typing accuracy and speed, measured by the number of

mistakes and time of task completion, this task analyzes how brightness and color temperature influence physical engagement and cognitive performance during repetitive tasks. c) **Gaming on a Computer** introduces an interactive component by having participants play Tetris, starting at level 5, for three minutes. This game requires rapid decision-making, hand-eye coordination, and visual precision, making it an ideal task for assessing the effects of lighting on dynamic stimuli and cognitive focus. Level 5 of the online game introduces a moderate challenge, as the falling speed of the Tetris pieces increases significantly compared to earlier levels, requiring quicker decision-making and faster reaction times, but still allowing room for strategic placement and maneuvering. The task provides insights into how lighting supports fast-paced, keyboard-driven interactions while minimizing visual fatigue.

For tasks involving physical media, **Reading on Paper** evaluates the impact of lighting on text clarity and shadow minimization. Participants read a printed paragraph and answer comprehension questions, focusing on how lighting affects readability under direct and ambient light sources. Similarly, **Puzzle on Paper**, which involves completing a 10–12 word search, tests visual clarity, problem-solving skills, and sustained attention under each lighting profile.

Finally, **Sketching on Paper** explores how lighting affects creative tasks requiring precision and focus. Participants will sketch simple objects, with prompts changing for each lighting profile to maintain a consistent level of cognitive effort while preventing anticipation bias. This task evaluates how lighting minimizes shadows and enhances visual clarity for intricate manual work.

After completing each task, participants will fill out a customized questionnaire to provide additional insights into their experience under each lighting profile. These questionnaires will evaluate eye comfort and strain, the perceived quality and tone of the lighting, and the lighting's impact on focus, mood, and overall task performance. By integrating these subjective evaluations with the measurable outcomes (time competition, error and accuracy rates) of each task, the study aims to generate a holistic understanding of how lighting affects cognitive and physical engagement in diverse workspace scenarios. Together, this comprehensive approach directly aligns with the study's objective to develop adaptable and effective lighting solutions tailored to user needs.

IMPLICATIONS FOR PROTOTYPE DEVELOPMENT

The findings of this study have significant implications for the development of the smart desk lighting system prototype. Customization will be the central focus, with user-friendly controls enabling seamless adjustments to brightness, tone, and color to suit individual preferences and task requirements. Integration is another key priority and a challenge; the system will be designed to complement natural light, ensuring a balanced workspace environment while providing smooth transitions between various lighting profiles for different activities. Finally, in-person testing will play a crucial

role in validating the system's effectiveness. These testing sessions will provide valuable user feedback, which will guide iterative refinements to ensure that the final design aligns with user needs and enhances productivity, comfort, and overall well-being.

CONCLUSION

This study underscores the transformative potential of integrating color theory and user-centered design into workspace lighting systems, addressing critical gaps in traditional solutions. By prioritizing adjustability, color-customizable features, and ergonomic considerations, the proposed design bridges the divide between functionality and aesthetic appeal. It not only supports task-specific performance but also enhances emotional and cognitive well-being, reflecting the growing demand for holistic solutions in workspace design. It underlines the need to study the effect of emotional states on the task-specific performance under the context of lighting.

From an industrial design perspective, this research reinforces the necessity of adaptability and user-centric solutions. Traditional lighting systems have historically prioritized basic functionality, often neglecting the psychological and emotional dimensions of light (IES, 2021). By incorporating features such as RGB lighting and customizable brightness, the proposed system elevates workspace lighting, offering users greater flexibility, personalization and a chance to explore their definition of comfort (Norman, 2013). These elements align with modern design principles of balancing functionality, usability, and aesthetic appeal, setting a new benchmark for products that combine practicality with visual and emotional resonance.

In the realm of human factors, the findings (Smolders & de Kort, 2014) emphasize the critical importance of ergonomic considerations, such as glare reduction and flexible positioning, to enhance user comfort and efficiency. Furthermore, the study validates the need to address cognitive and emotional needs alongside physical ones. Dynamic lighting profiles that adapt to tasks and times of day align with circadian rhythms, fostering mental alertness during focused work and relaxation when transitioning to less demanding tasks. This dual functionality highlights the broader implications of the study for creating healthier and more engaging workspaces.

Compared to existing systems, the proposed multi-component lighting system, featuring desk lamps, light bars, floor lamps, and wall panels, offers seamless adaptability with precise control over brightness, color temperature, and hue. Unlike existing systems, it effectively integrates natural and artificial lighting to enhance productivity and create a healthier, more engaging workspace.

In the wake of these advancements, the study acknowledges several potential challenges and limitations in real-world implementation. Manufacturing costs for advanced features, such as RGB lighting and circadian-friendly adjustments, could limit accessibility. Additionally, some users may find the system's customization options overwhelming, especially if they are accustomed to static lighting solutions and thus implore for more research. Ensuring compatibility with diverse workspace configurations

and addressing environmental concerns, such as energy consumption and material sustainability, are critical next steps. Future iterations of the prototype must balance advanced functionality with cost-efficiency, usability, and eco-friendliness to ensure broader applicability and long-term success.

Ultimately, this research lays a robust foundation for future exploration and prototype development, and its findings pave the way for innovative lighting solutions that redefine modern work environments, offering a harmonious blend of functionality, aesthetics, and user-centered innovation. This integrated approach positions the design to make a lasting impact on how workspaces are illuminated and experienced.

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